Wind and Seismic Effects

Proceedings of the 30th Joint Meeting

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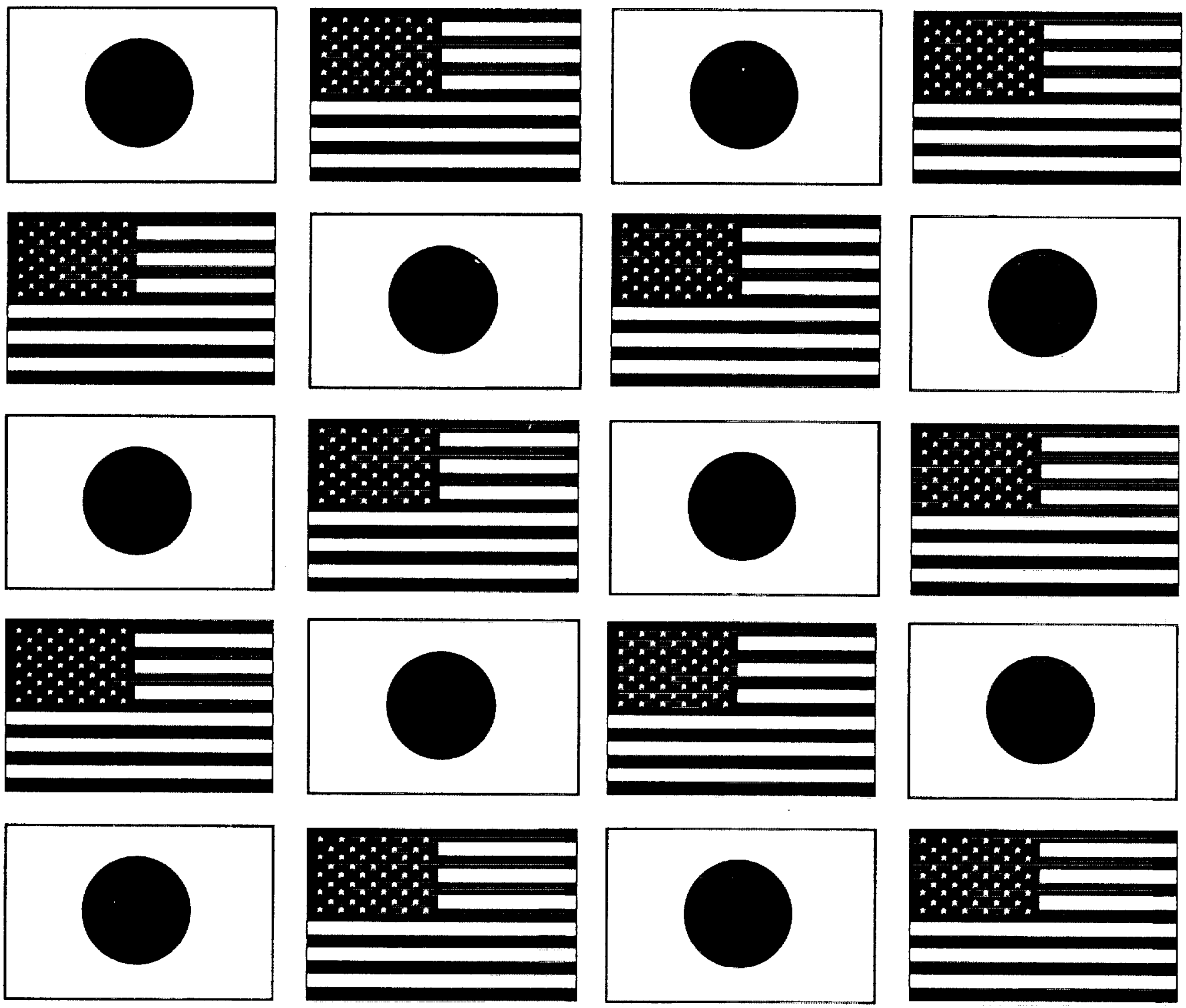

U.S. DEPARTMENT OF COMMERCE
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Wind and Seismic Effects

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PANEL ON WIND AND
SEISMIC EFFECTS

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Development of New High Bridge Piers Containing Spiral Reinforcement

by

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ABSTRACT

The construction of expressway and other arterial roads in Japan is shifting from those running the length of the Japanese Archipelago to roads across its islands, a change in emphasis that has increased the number of roads constructed through mountainous regions of the country. Recent years, a strong demand for the preservation of natural environments has been accompanied by the need for bridge construction methods that have minimal effects on nature. To meet this new requirement, high bridge piers must be constructed.

In response to these circumstances, rationalize execution and to develop the 3H (Hybrid Hollow High Pier) Method: a new high bridge pier structure that is both economical and provides earthquake resistance.

Kye Words: High Pier

Spiral Reinforcement

Development of Construction

Performance Confirmation Tests

1. INTRODUCTION

The construction of expressway and other arterial roads in Japan is shifting from those running the length of the Japanese Archipelago to roads across its islands, a change in emphasis that has increased the number of roads constructed through mountainous regions of the country. Past roads through mountainous areas included many sections constructed by means of large scale cutting and embankment work. But in recent years, a strong demand for the preservation of natural environments has been accompanied by the need for bridge construction methods that have minimal effects on nature. To meet this new requirement, high bridge piers must be constructed. And the work performed to construct bridge piers must include environmental measures such as cutting less soil and reducing the size of execution yards. It is also necessary to reduce labor requirements and the quantity of work performed to deal with both a shortage of and an increase in the average age of skilled construction workers.

During the Hyogo-ken Nanbu Earthquake of 1995, road bridges that play important roles as evacuation routes and emergency transportation arteries, were destroyed with serious effects on the life of local society. It is now essential to develop new kinds of bridge piers that provide earthquake resistance superior to that of conventional reinforced concrete bridge piers.

In response to these circumstances, the Public Works Research Institute of the

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Ministry of Construction has worked in cooperation with the Advanced Technical Center, and private companies to rationalize execution and to develop the 3H (Hybrid Hollow High Pier) Method: a new high bridge pier structure that is both economical and provides earthquake resistance.

2. OUTLINE OF THE 3H METHOD

2.1 Present Problems and Development Goals

Most high bridge piers now designed and constructed are reinforced concrete bridge piers. Extremely large quantities of steel reinforcing material is used in order to minimize their cross section dimensions. The revision to the Road Bridge Guidelines completed in 1996 stipulates that bridge piers shall be provided with sufficient stiffness by installing highly concentrated hoop ties and intermediate hoop ties. This has made execution of bridge piers extremely difficult, resulting in many problems related to construction periods and costs. It is also necessary to guarantee safe execution at high work locations.

In response, technical development has been undertaken in an effort to improve high bridge piers by

(1) increasing execution efficiency,
(2) improving bridge pier earthquake resistance,
(3) preserving the environment,
(4) cutting costs, and
(5) improving the quality and appearance of the work.

2.2 Structure of a 3H Method Bridge Pier

Figure 1 through Figure 4 present an outline of the structure of 3H Method bridge piers.

The most important distinguishing feature of the structure of a 3H Method bridge pier is the fact that part of the axial direction reinforcing rods installed with the conventional method are replaced with steel (H-steel or steel pipes). As Figure 3 and Figure 4 show, the intermediate hoop ties are replaced with spiral reinforcement. This spiral reinforcement forms a spiral column consisting of the steel and axial direction reinforcement surrounding it. Figures 5 and 6 show spiral columns. These are installed around the full circumference of the bridge pier section to form the bridge pier column. Because this is a steel - reinforced concrete structure that includes steel material, its buckling load carrying capacity is greater than that of a reinforced concrete structure. This permits a reduction in the decline in its bearing strength after maximum load during bending behavior. And by closing the axial direction reinforcement, the spiral reinforcement confines the buckling of the steel reinforcement generated during large deformation of the bridge pier. This provides the same function as intermediate hoop ties. These features improve the toughness of bridge piers. It is also possible to construct bridge piers with far greater earthquake resistance than that of conventional bridge piers.

2.3 3H Method Execution Procedure

The 3H method execution has been developed basically by effectively combining existing technologies. It is also more rational than past methods of constructing bridge piers. It is extremely important, however, to make sure that the initial assembly of the spiral columns is performed precisely. And to reduce labor, the spiral columns must be as long as possible. Depending on the bridge pier height and other construction conditions, appropriate measures must be take to prevent vibration, oscillation, etc. of the spiral columns during execution.

Execution methods can be broadly categorized into the following two methods depending upon the type of forms used.

2.3.1 Execution Method Using Precast Forms

This execution method is used mainly to build high bridge piers with a height ranging from 30 to 60 meters. Because precast forms are used on the inside and outside surfaces of the bridge pier, it is the best method from the viewpoint of execution properties, quality, and appearance.

The execution is performed by first installing the spiral columns, assembling the precast forms into appropriate units on land, using a crane to lower the units into place, then anchoring them. Finally, the spaces between the precast forms are filled with secondary concrete.

2.3.2 Execution Method Using Movable Forms

This execution method is used mainly to construct bridge piers higher than 50 meters in height. The use of large movable forms permits improved execution properties and shorter work periods.

With this method, the spiral columns and hoop ties are installed, then jacks are used to simultaneously or alternately raise the forms and the scaffolding in order to construct the bridge piers.

2.4 Special Features of the 3H Method

The following are the special features of the structure and the execution method described above.

(1) More Efficient Execution

- Replacing part of the axial direction reinforcement with H-shaped steel, steel pipes, or other steel material sharply reduces the quantity of complex reinforcing work that is necessary. This can bring substantial improvements in execution efficiency and speed up the execution.
- The use of spiral columns can eliminate the work required to install intermediate hoop ties.
- The use of precast forms or large movable forms also contributes to more efficient execution.

(2) Improving Earthquake Resistance

It is a steel - reinforced concrete structure built by replacing part of the axial direction reinforcement with H-shaped steel or steel pipes to provide buckling load carrying capacity and toughness superior to that possible with a reinforced concrete structure.

(3) Environmental Protection

- The use of precast forms or large movable forms can reduce the quantity of natural resources consumed.
- The method can reduce the size of execution yards, mitigating the effects of the work on the surrounding environment.

(4) Cost Reductions

- More efficient execution shortens construction periods, lowering costs.

(5) Improved Quality and Appearance

- The use of factory made or processed structural members contributes to more dependable quality and more attractive bridges.

3. PERFORMANCE CONFIRMATION TESTS CONDUCTED TO DEVELOP NEW TECHNOLOGY

In order to develop the 3H Method, it was necessary to accurately clarify previously unknown dynamic properties and their behavior. The authors have performed element tests of several kinds. These tests have confirmed that the 3H Method has properties equal or superior to those of the conventional method.

And loading tests of conventional reinforced concrete structures and structures made using the 3H method were performed with models 1/4 the size of real bridge piers.

The remainder of Section 3. describes the tests and their results.

3.1 Column Specimens

3.1.1 Outline of the Test

The specimens modeled part of the hollow cross section of bridge piers. With dimensions of 1,600 × 450 × 1,700, they were about 1/2 the size of those of an actual bridge. The test cases are shown in Table 1 and outlines of the specimens are shown in Figure 7. Case 1 (standard specimen) represented a conventional reinforced concrete structure; Cases 2 through 7 represented steel - reinforced concrete structures made using H-shaped steel; Cases 8 and 9 represented steel - reinforced concrete piers made using steel pipes; and Case 10 represented a reinforced concrete bridge pier made using spiral reinforcement. Cases 2 through 9 were tested by varying factors such as the pitch of the spiral reinforcement, the intervals between the columns, and the axial direction reinforcement ratio (percentage of the total steel cross section area accounted for by the axial direction reinforcing steel area), the hoop tie pitch, etc. The total steel material section areas in the steel - reinforced concrete structures and the reinforced concrete structures were almost identical and the axial direction reinforcement ratio in the steel - reinforced concrete structure was about 10%.

The tests were performed by monotonically increasing the vertical load and measuring the displacement of the specimens in the height direction and the strain etc. of the steel reinforcement.

3.1.2 Test Results

Fracturing of the specimens in every case occurred in the form of cracking of the concrete surface in the loading direction at the ends and in the middle of the specimens. As the load increased, the centers of the specimens bulged out at right angles to the loading direction. Afterwards, the protective concrete covering peeled off, and the testing ended when the axial direction reinforcement buckled. Photographs 1 and 2 show the way that the H-shaped steel and steel pipes fractured.

Table 2 summarizes the test results. The strength ratio (P/σ) that clarifies the bearing strength in each case compared the maximum stress found from the maximum load and the concrete strength of the test pieces. The following information is revealed by this strength ratio.

(1) In Case 2 through Case 4, the confining effects of the spiral reinforcement provided maximum stress almost equal to that in Case 1 where intermediate hoop ties were used. And only slight differences were observed in the maximum stress and strength ratio as a result of the pitch of the spiral reinforcement.

(2) Case 3 and Case 5 reveal that the intervals between columns has almost no effect on the maximum stress.

(3) Case 3 and Case 7 reveal that as the interval between the hoop ties is increased, the maximum stress declines by about 30%.

Figure 8 shows the strain of the spiral reinforcement at about the center of the Case 2 specimen. Up to maximum load, the strain in the middle (S12, S12) was highest. But the strain of the spiral reinforcement at that time ranged from 1,000 to 1,500 μ , which was less than the yield strain (between 1/7 and 1/5 of approximately 7,300 μ). At the stage where the continued loading had reduced the load to about 80% of the maximum load, the strain of the spiral material in a part corresponding to the intermediate hoop ties (S2, S7, S15) abruptly increased. This spiral reinforcement displays behavior typical of intermediate hoop ties.

Figures 9 and 10 show the displacement at right angles to the load direction in the center of the specimens. In Case 2 and Case 3, displacement did not increase immediately after the maximum load, then after the load fell to about 80%, displacement began.

In Case 7 where the hoop tie pitch was 150 mm, displacement began immediately after maximum load. And even in Case 5 where the column interval was large, displacement occurred immediately after maximum load just as it did in Case 7. These results reveal that the pitch of the spiral reinforcement, column interval, and pitch of the hoop ties provide deformation confinement in the lateral direction that can be counted on to provide effects that substitute for those of intermediate hoop ties.

Figure 11 presents the relationship between the stress and the strain when the pitch of the spiral reinforcement is varied. Little change was observed in either the maximum stress or the behavior after maximum stress as the pitch of the spiral reinforcement was varied. From a specimen strain near 3,000 μ , the greater the pitch of the spiral reinforcement, the higher the percentage that the stress declined. And in these cases, even at the stage where the specimen strain reached 10,000 μ , the specimen's stress remained at 150 kgf/cm^2 or more. This confirmed its superior deformation properties.

Figure 12 presents the relationship between the stress and the strain when the pitch of the spiral reinforcement is held constant while other conditions are varied. When the pitch of the hoop ties was large at 150 mm, the maximum stress of the specimens declines sharply. But if the strain of a specimen surpasses approximately 3,000 μ , the percentage decline of the stress is almost identical in every case.

Figure 13 presents the relationship between the stress and strain in three cases: principal steel is H-shaped steel + axial direction reinforcement (Case 4), steel pipe + axial direction reinforcement (Case 9), and only axial direction reinforcement (Case 10). This figure reveals that differences in the kind of principal steel used have little effect on the maximum stress of the specimens nor on the strain of the specimens at maximum stress. But when the maximum stress is exceeded, the stress declines more when only axial direction reinforcement is used than it does in other cases.

3.1.3 Summary

The study was performed to confirm the performance of "steel reinforced concrete plus spiral reinforcement": the basic structure of a 3H bridge pier. The results have confirmed that the basic structure of a bridge pier made using the 3H Method provides axial compressive strength equal to that of conventional bridge piers and superior deformation properties.

3.2 Alternating Loading Tests

3.2.1 Outline of the Tests

Figure 14 presents cross sections and dimensions of specimens that are scaled down replicas of real bridges and outlines of the tests. The modeling was done by arranging the axial direction steel to obtain the same bending bearing strength as models of conventional bridge piers. The testing was done by applying axial force corresponding to the dead load from the superstructure. Afterwards, the horizontal displacement at the loading point when the axial direction reinforcement and the steel at the outside edge of the cross section of the bridge pier foundation reached the yield value was set at 1 δ y. The displacement of this integral multiple was loaded alternately negatively and positively under displacement control. And the number of repetitions at each loading step was set at 3.

3.2.2 Test Results

Figures 15 through 17 show the hysteresis curves of the horizontal load - horizontal displacement of the conventional method and the 3H Method (models with H-shaped steel and steel pipes), while photograph 3 presents a view of the test. The displacements at about 1 δ y where the tensile side steel reached the yield value were almost identical at about 15 mm for both the conventional method model and 3H Method model. The maximum bearing strength was a little higher in the case of the 3H Method model. Both methods provide sufficient deformation performance. But the percentage decline in the bearing strength during large deformation seems to have been smaller in the 3H Method model case. And a comparison of the shapes of the hysteresis curves reveals spindle-shapes with superior energy absorption in both cases. The area of the hysteresis loop of the 3H Method model is clearly larger than that of the conventional method model. And because a reversed S-shaped slip is not observed, it is concluded that its earthquake resistance is greater than that of the conventional method.

Detailed analysis is now in progress.

4. CONCLUSIONS

The 3H Method can substantially reduce labor requirements from the level necessary to implement the conventional method.

Various element tests and negative - positive alternating horizontal loading tests using specimens that are scaled down models of real bridges that have already been performed have clarified the structural properties of piers constructed using the 3H Method. But because it is a new type of structure, some aspects of its execution are still not clearly understood. The next task is to incorporate knowledge of these points obtained from future executions in design, execution, and estimation manuals as it is obtained.

Table 1. Test Cases

No.	Structure	Steel Material (Number)	Axial Direction Reinforcement (Number)	Axial direction Reinforcement Ratio (%)	Hoop Ties Diameter, Pitch (mm)	Spiral Reinforcement Diameter, Pitch (mm)	Spiral Reinforcement Column Interval (mm)
1	RC	—	D25 × 42	100	D10 × 75	—	—
2	H-shaped Steel	H-200 × 3	D16 × 16	14.3		ϕ 5.1 × 75	100
3						ϕ 5.1 × 100	
4						ϕ 5.1 × 150	
5						ϕ 5.1 × 100	200
6		H-150 × 3	D25 × 16	40.2			100
7		H-200 × 3	D16 × 16	14.3	D10 × 150		
8	Steel Pipe	ϕ 216 × 3		16.5	D10 × 75	ϕ 5.1 × 75	
9						ϕ 5.1 × 150	
10	RC	—	D25 × 40	100		ϕ 5.1 × 100	

Table 2. Test Results

No.	Structure	Maximum Load F (tf)	Equivalent Cross Section Area A (cm^2)	Maximum Stress P F/A (kgf/cm^2)	Concrete Strength σ (kgf/cm^2)	Strength Ratio P / σ
1	RC	1797	9619	187	164	1.14
2	H-shaped Steel	2157	8995	240	218	1.10
3		2129	9041	235	214	1.10
4		2093	8887	236	223	1.06
5		2176	9052	240	214	1.12
6		2156	8816	245	242	1.01
7		1919	9092	211	257	0.82
8	Steel Pipe	1854	8613	215	231	0.93
9		1934	8620	224	231	0.97
10	RC	2027	8646	234	245	0.96

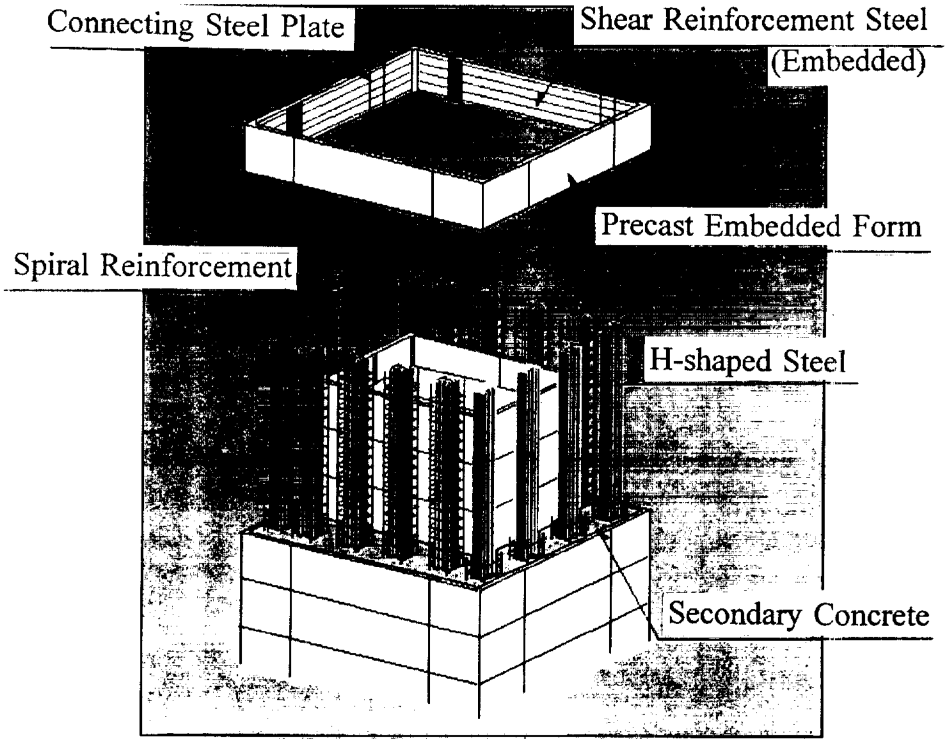


Figure 1. Precast Form Structure

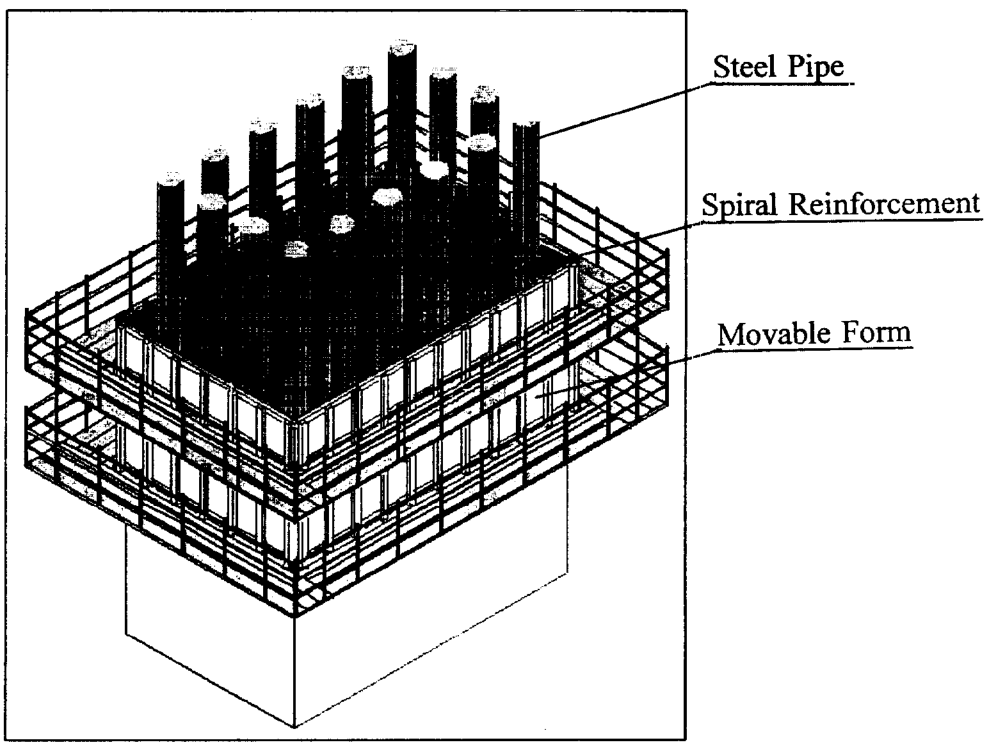
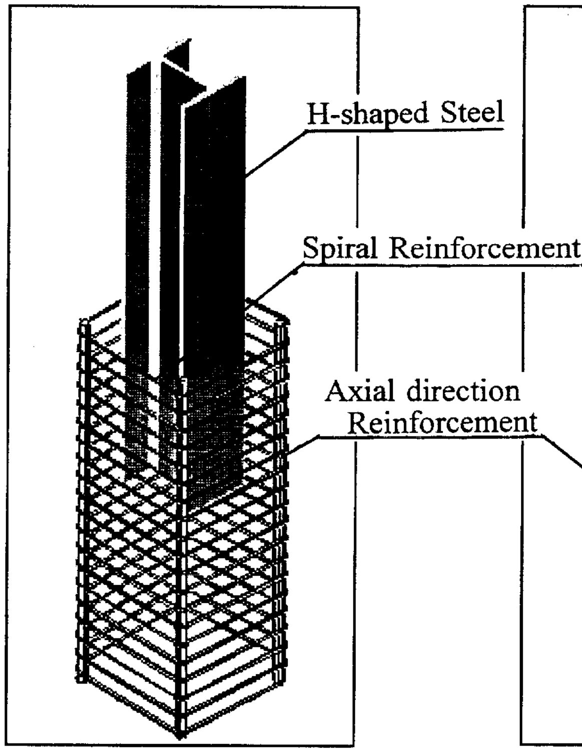


Figure 2. Movable Form Structure



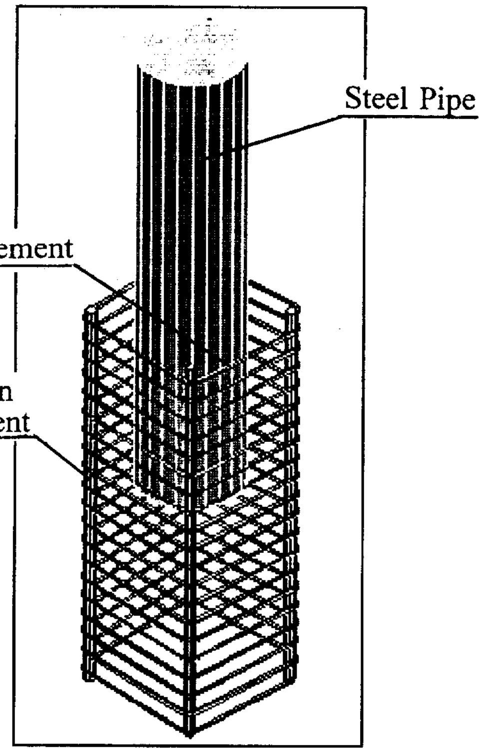


Figure 3. H-shaped Steel Type **Figure 4. Steel Tube Type**

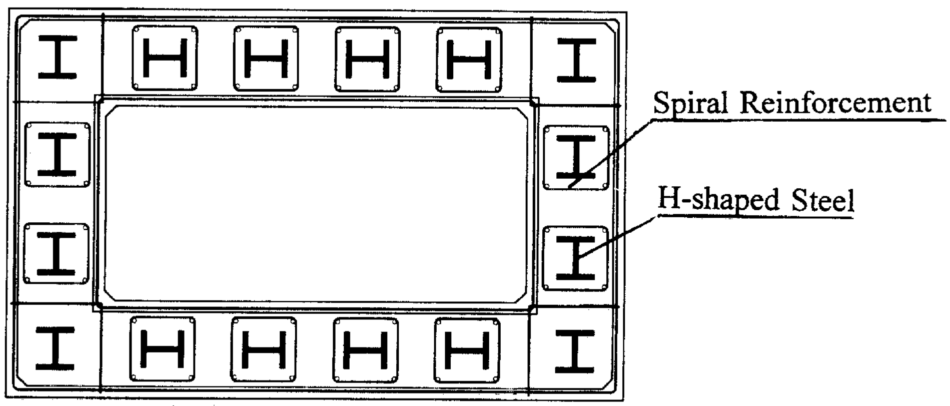


Figure 5. H-shaped Steel Type Arrangement Diagram

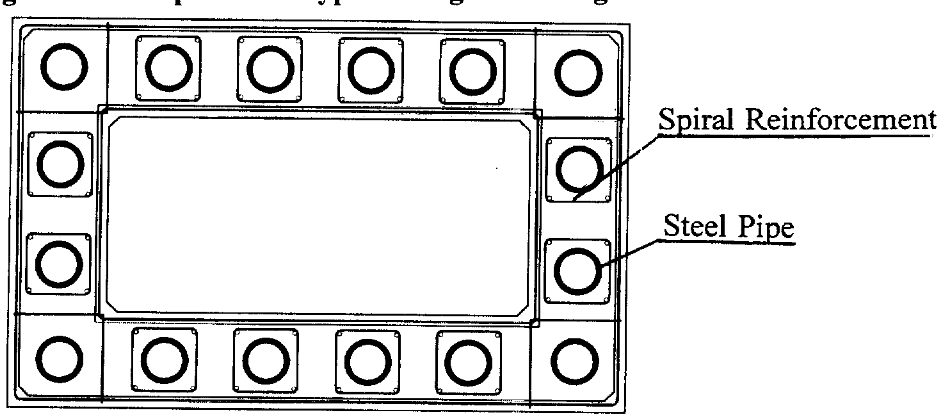
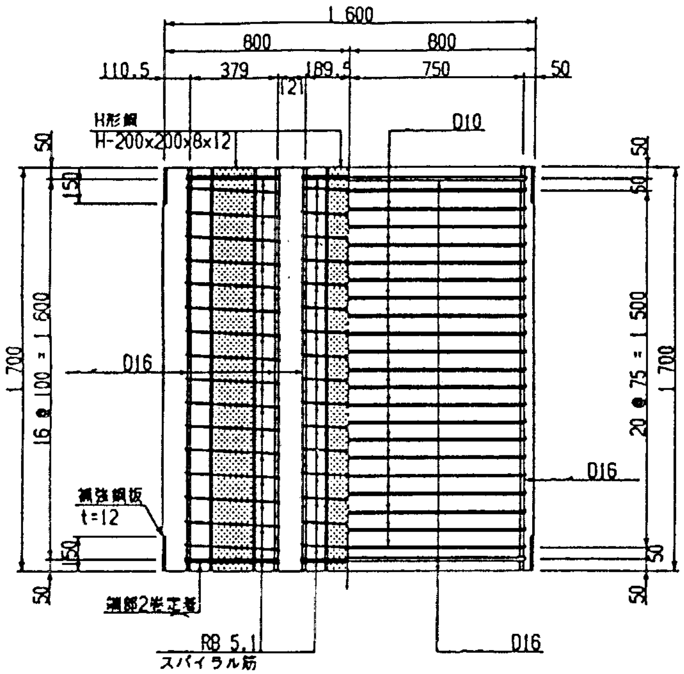
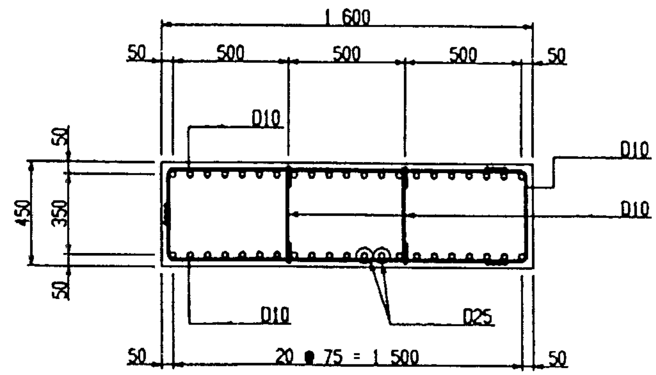
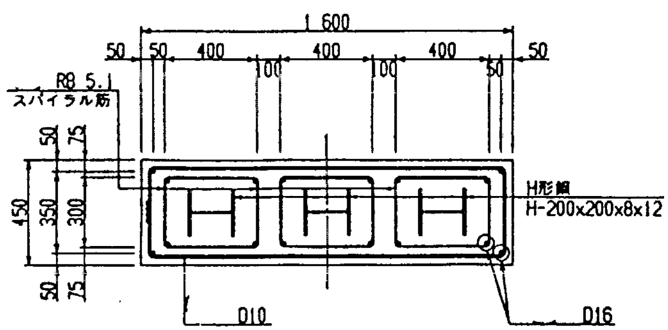


Figure 6. Steel Tube Type Arrangement Diagram

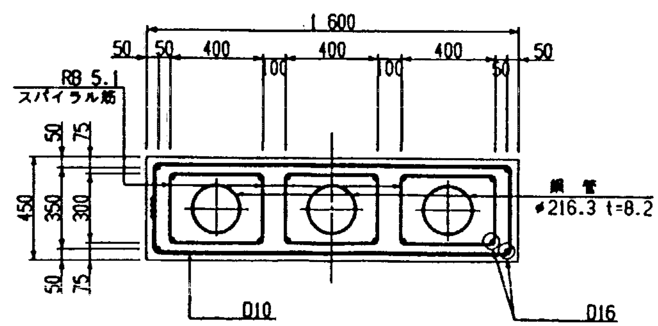




Specimen Cross Section (Case 1: Standard Specimen)



Specimen Reinforcement Diagram (Case 3)



Specimen Cross Section (Case 9)

Figure 7. Outline of Specimens

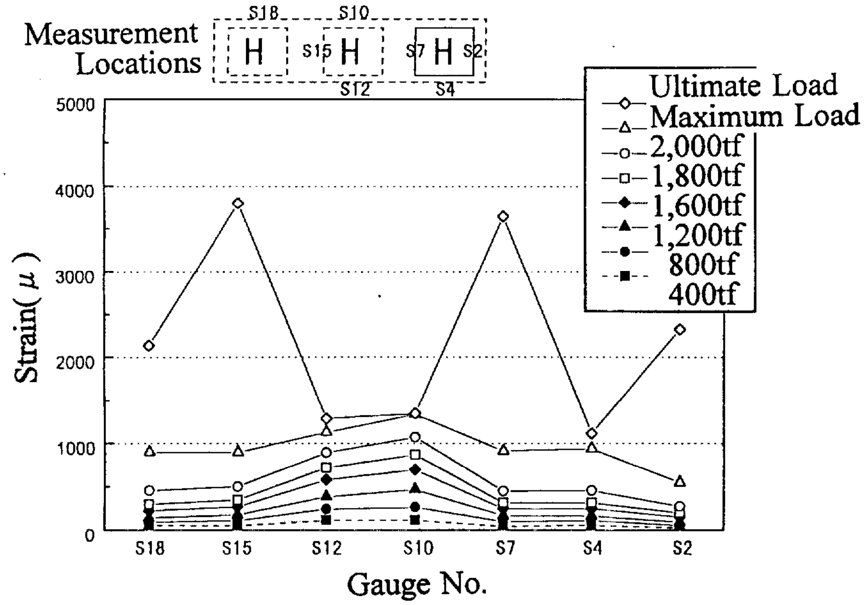


Figure 8. Strain Distribution of Spiral Reinforcement

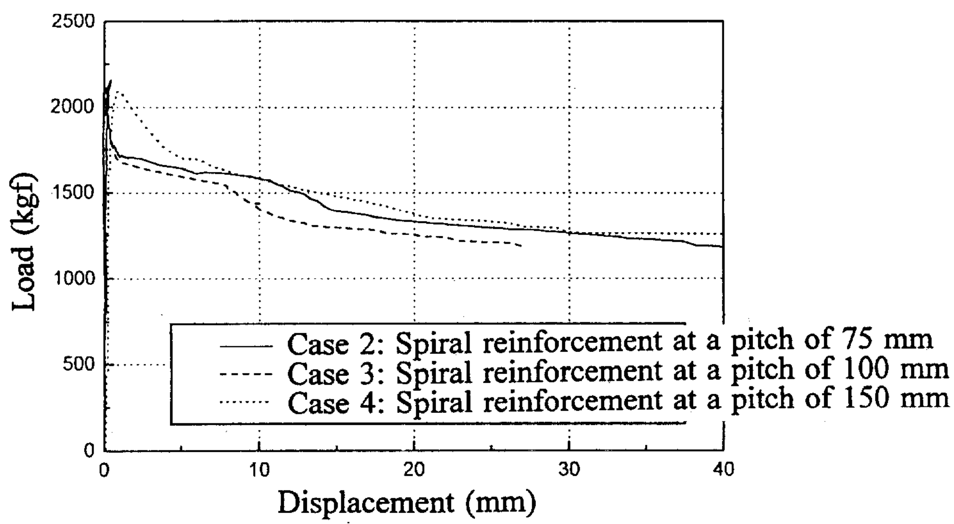


Figure 9. Load - Displacement Under Varying Spiral Reinforcement Pitch

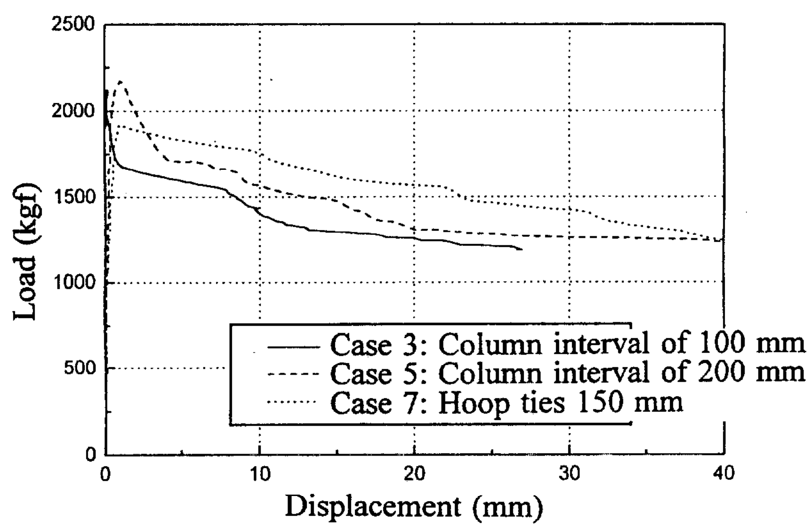


Figure 10. Load - Displacement Under Varying Conditions

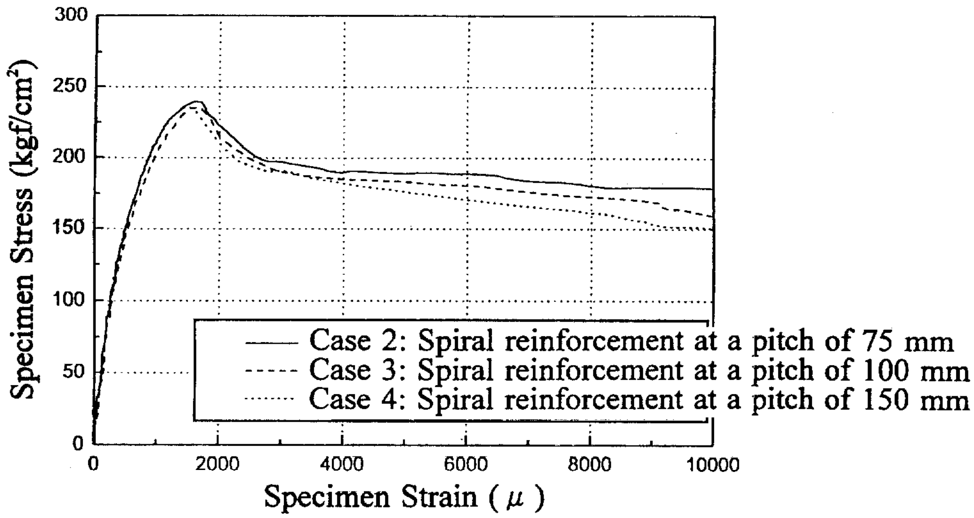


Figure 11. Stress - Strain Caused Under Varying Spiral Reinforcement Pitch

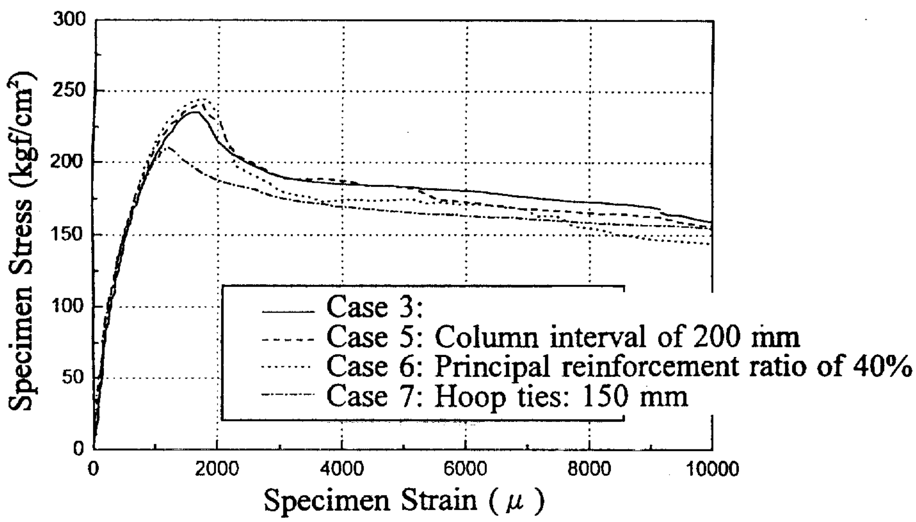


Figure 12. Stress - Strain Under Varying Conditions

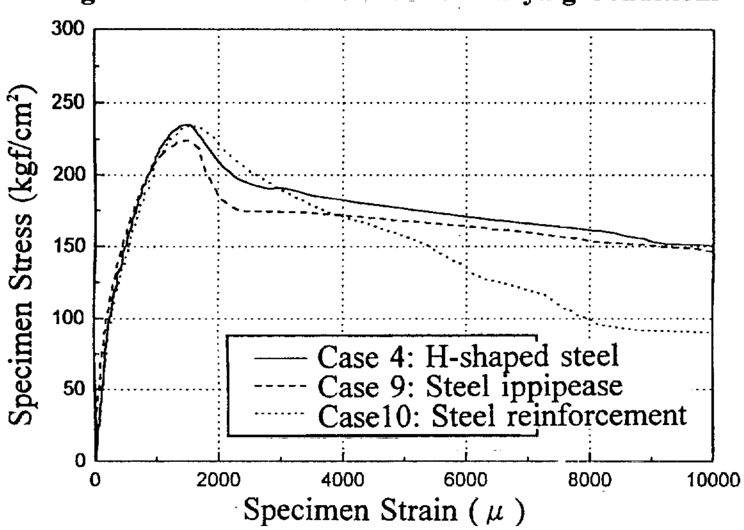


Figure 13. Stress - Strain Under Varying Principal Steel

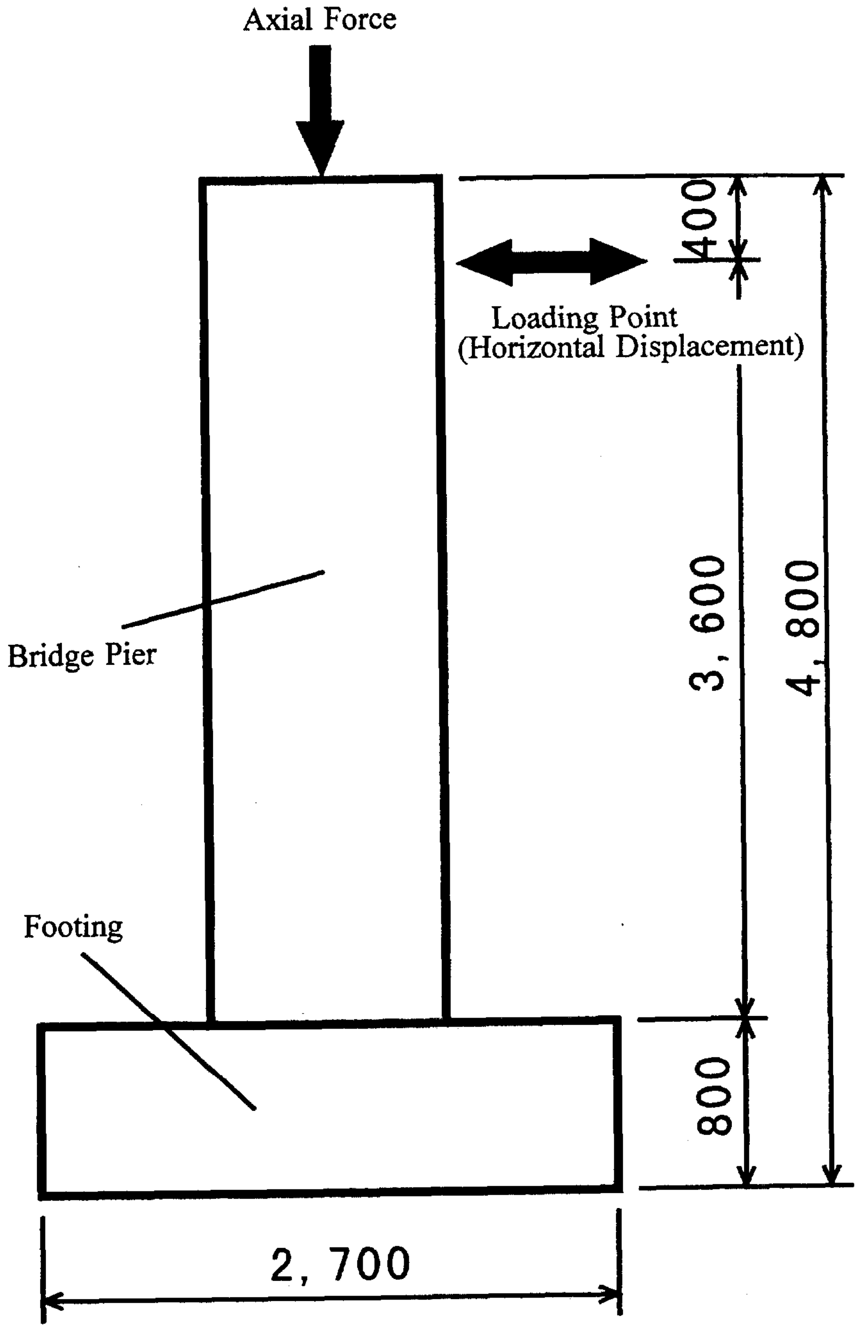


Figure 14. Alternate Loading Testing: Outlines of the Specimens

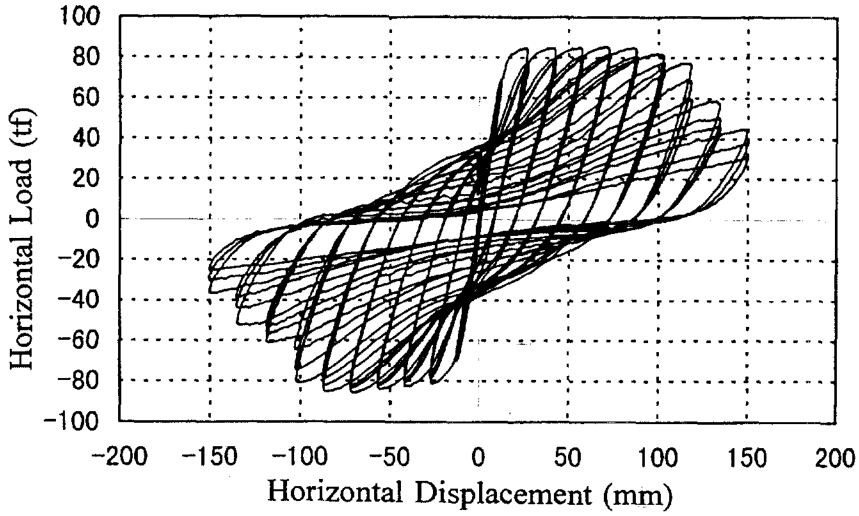


Figure 15. Alternate Loading Testing: Conventional Method

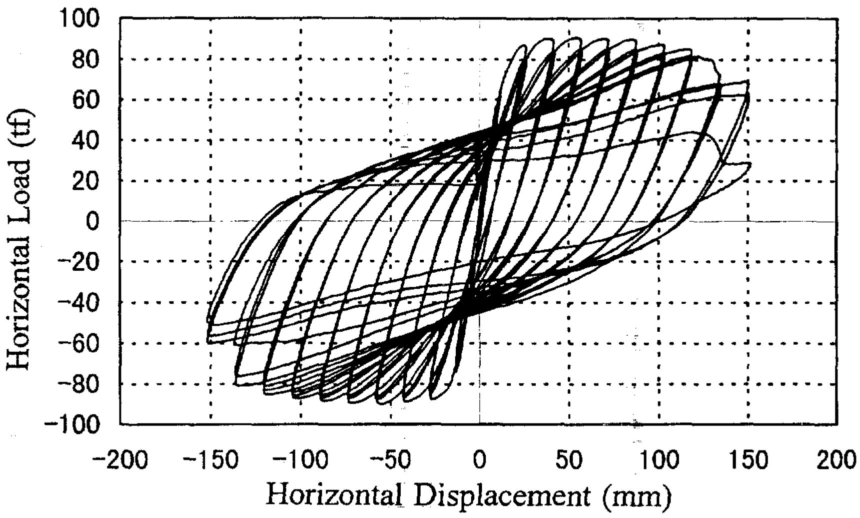


Figure 16. Alternate Loading Testing: H-shaped Steel Model

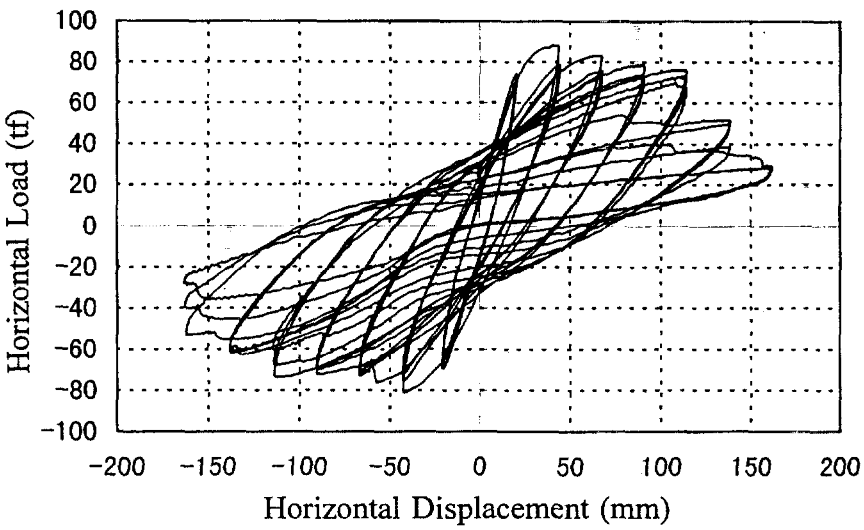
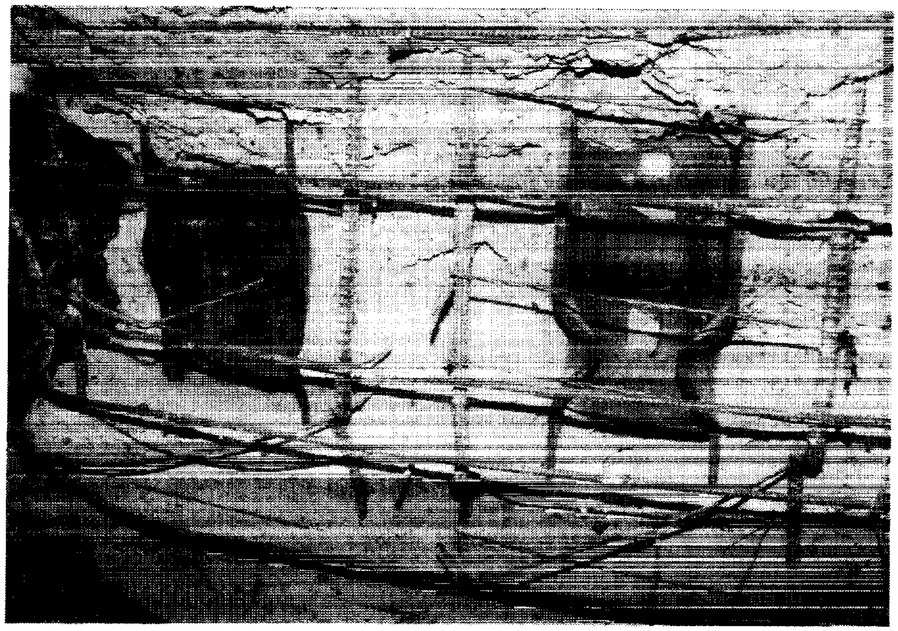
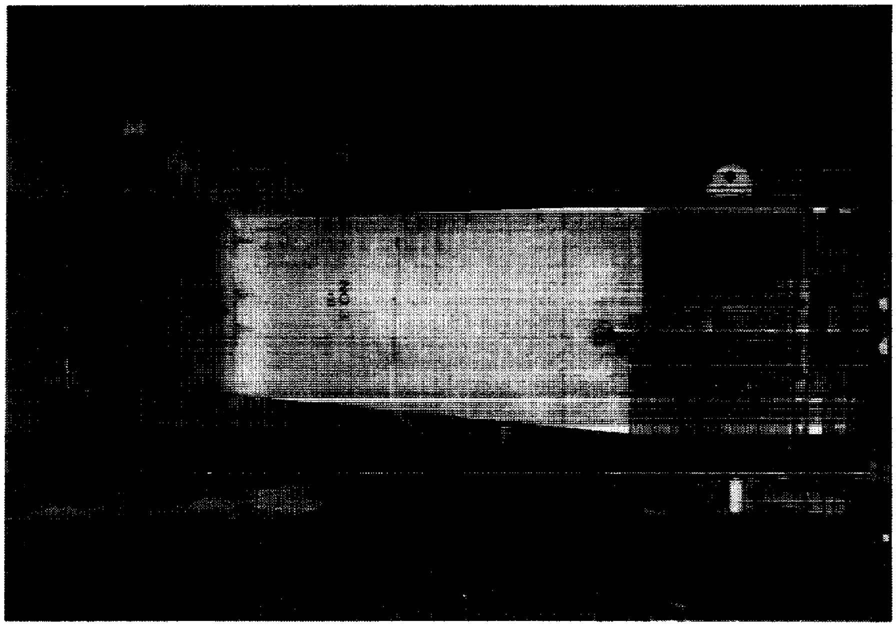


Figure 17. Alternate Loading Testing: Steel Tube Model

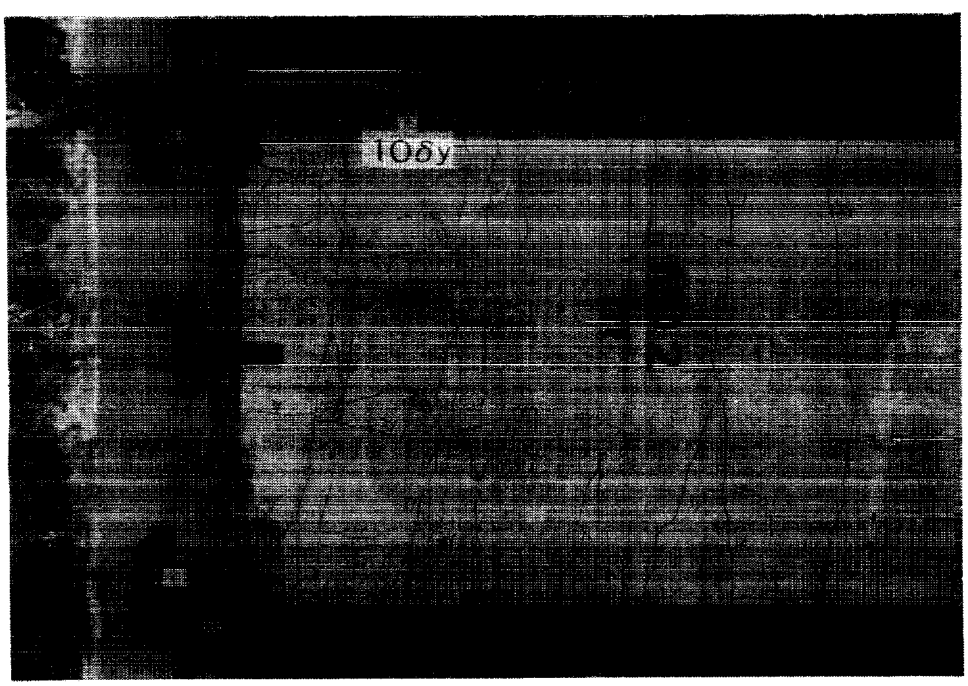


Photograph 1. Fracturing of H-shaped Steel

Photograph 2. Fracturing of Steel Pipe



Photograph 3. Alternate Loading Testing



Photograph 4. Case2 H-shaped Steel 10 δ y